REMARKS/ARGUMENTS

Claims 6-24 and 35-55 are pending in the Application.

Claims 35-55 have been withdrawn.

Claims 6-24 stand rejected.

Claim 12 is objected to.

Claims 14 and 35-55 are cancelled herein.

Claims 6 and 12 are amended herein.

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I. ELECTION/RESTRICTIONS

Claims 35-55, previously withdrawn, are hereby cancelled.

II. CLAIM OBJECTIONS

Examiner has objected to the dependency of Claim 12. Accordingly, Applicant has amended Claim 12 to depend from Claim 8. Applicants note that Claim 12 was not amended to overcome prior art. Hence, no prosecution history estoppel arises from the amendment of Claim 12. *Festo Corp. v. Shoketsu Kinzoku Kogyo Kabushiki Co.*, 62 U.S.P.Q.2d 1705, 1711-12 (2002); 56 U.S.P.Q.2d 1865, 1870 (Fed. Cir. 2000). Further, the amendment made to Claim 12 was not made for a substantial reason related to patentability and therefore no prosecution history estoppel arises from such an amendment. *See Festo Corp.*, 62 U.S.P.Q.2d 1705 at 1707 (2002); *Warner-Jenkinson Co. v. Hilton Davis Chemical Co.*, 41 U.S.P.Q.2d 1865, 1873 (1997).

III. REJECTIONS UNDER 35 U.S.C. § 102(E) AS ANTICIPATED BY *HASEGAWA*

Examiner has rejected Claims 6, 8-10, 12-17, 19 and 20 under 35 U.S.C. § 102(e) as being anticipated by Hasegawa et al., United States Patent No. 6,709,881 ("*Hasegawa*"). Examiner contends that "Hasegawa et al. discloses, as shown in Figures 5C-9, a device comprising: a substrate (11); nanostructures of wide bandgap material (14,15,16), wherein the nanostructures of wide bandgap material comprise an n-type portion (14) and a p-type portion (16) and wherein the nanostructures of wide bandgap material are selected from the group consisting of low-defect nanostructures of wide bandgap material, quantum confined nanostructures of wide bandgap material, surface confined nanostructures of wide bandgap material, and combinations thereof." Office Action, at 2-3.

Claim 6 has been amended to further include the limitations of Claim 14, namely that the nanostructures be in the form of quantum dots and/or quantum wires. Applicant points out that such structures are nanoscale in at least two dimensions. No new matter is introduced as a result of such amending.

Hasegawa is directed to methods that "easily and reliably control an etching process on a group III-V compound semiconductor" by providing "an etching stop layer in at least a portion of an area under a group III-V compound semiconductor to be etched." *Hasegawa*, col. 1, line 67 - col. 2, line 5. In some embodiments of *Hasegawa*, such semiconductors can be used in the manufacture of a semiconductor laser device. *Hasegawa*, col. 5, lines 13-18. Applicant points out that *Hasegawa* does not teach nanostructures of wide bandgap material that are nanoscale in at least two dimensions, as are the quantum dot and quantum wire nanostructures of the present invention—as put forth in amended Claim 6. Parts 14-16 (*Hasegawa*, Figs. 1-6, and 8) of *Hasegawa* to which Examiner points are layers of semiconductor having nanometer thickness. While in some embodiments of *Hasegawa* these semiconductor layers are "quantum wells" (when they are sufficiently thin), they are at best nanoscale in only a single dimension.

Applicant points out that all lithography described in *Hasegawa* is conventional photolithography, with the smallest patterned structural features having dimensions on the order of a couple of micrometers. *Hasegawa*, col. 6, lines 61-67. Thus, any structural features produced by such lithography cannot be nanoscale in more than a single dimension. In contrast, there is a recognition in the present Application that such conventional photolithography is insufficient to generate such functional nanostructures, and that one or more nano-patterning techniques, such as block co-polymer lithography, e-beam lithography, extreme ultraviolet lithography, etc., are required to generate the pre-patterned substrate in which the nanostructures can be grown. See Application, p. 10, para. 41. Accordingly, amended Claim 6 is not anticipated by *Hasegawa*.

Regarding Claim 8, Examiner contends that "Hasegawa et al. discloses the device further comprising a nucleation layer (12) interposed between the substrate and the nanostructures of wide bandgap material." Office Action at 3.

Referring to Figure 1 of the Application, Applicant respectfully points out that a nucleation layer 102, as defined in the Application, is used to grow monolithic nanostructures 105 in a patterned nanostructured template 104, the nanostructured template comprised of a dielectric layer 103 residing on the nucleation layer, and the dielectric layer having been patterned with a nano-lithographic technique. The purpose of such a nucleation layer 102 is to nucleate growth of nanostructures in the nanostructured template 104 using growth techniques such as chemical vapor deposition, molecular beam epitaxy, etc. See Application, p. 10, para. 42. The layer (12) to which the Examiner points in *Hasegawa* is neither referred to, nor used as, a nucleation layer within the context of the definition put forth in the present Application. Accordingly, Claim 8 is not anticipated by *Hasegawa* for the same reasons as amended Claim 6 (from which it depends) and also because *Hasegawa* fails to teach a nucleation layer.

Regarding Claims 9, 10, 12, and 13, such claims depend directly from either amended Claim 6 or Claim 8 (which depends from Claim 6). Accordingly, Claims 9, 10, 12, and 13 are not anticipated by *Hasegawa* for the same reasons that amended Claim 6 and Claim 8 are not anticipated by *Hasegawa* (see above).

Regarding Claim 14, the Examiner contends that "Hasegawa et al. discloses the wide bandgap nanostructures are selected from the group consisting of quantum dots, quantum wires (or layers) (which is MQW), and combinations thereof." Office action at 4.

Amended Claim 6 includes the additional limitations of Claim 14, namely that such nanostructures be quantum dots and/or quantum wires, both such structure types being nanoscale in at least two dimensions, and both such structure types comprising quantum confinement in at least two dimensions (see above). As amended Claim 6 is essentially Claim 14 re-written in independent form, Claim 14 has been cancelled. Applicant again respectfully points out that the layers of *Hasegawa* are not nanoscale in two or more dimensions and that quantum wells are in no way synonymous with quantum wires. Quantum wires are confined in two dimensions, whereas quantum wells are confined in only a single dimension. See D. Bimberg, M. Grundmann, and N. Ledentsov, *Quantum Dot Heterostructures*, John Wiley & Sons, New York, 1999, attached hereto as Exhibit A, for a discussion pointing out the differences between quantum wells, quantum wires, and quantum dots. Thus, while Claim 14 has been cancelled for the reasons outlined above, Examiner's original rejection of Claim 14 was improper because *Hasegawa* fails to teach either of quantum dots or quantum wires.

Regarding 15-17 and 19-20, all of these claims depend directly from amended Claim 6 and are not anticipated by *Hasegawa* for the same reasons that amended Claim 6 is not anticipated by *Hasegawa*.

As a result of the foregoing, Applicant respectfully requests that the Examiner withdraw the rejection of Claims 6, 8-10, 12, 13, 15-17, 19 and 20 under 35 U.S.C. § 102(e) as being anticipated by *Hasegawa*.

IV. REJECTIONS UNDER 35 U.S.C. § 103(A) AS OBVIOUS IN VIEW OF *HASEGAWA*

Examiner has rejected Claims 7, 11, 18 and 21-24 under 35 U.S.C. § 103(a) as being obvious in view of *Hasegawa*. Office Action, at 5.

Examiner is reminded that:

> To establish a *prima facie* case of obviousness, at least three basic criteria must be met. First, there must be some suggestion or motivation, either in the reference itself or in the knowledge generally available to one of ordinary skill in the art, to modify the reference. Second, there must be a reasonable expectation of success. Finally, the prior art reference must teach or suggest all the claim limitations. The teaching or suggestion to make the claimed combination and the reasonable expectation of success must both be found in the prior art and not based on Applicant's disclosure. *In re Vaeck,* 947 F.2d 488, 20 U.S.P.Q.2d 1438 (Fed. Cir. 1991); *see also* M.P.E.P §§ 2143-2143.03.

Regarding Claims 7 and 11, Examiner contends that "Hasagawa et al. discloses the claimed invention including the device as explained in the rejection above," and that while *Hasegawa* fails to disclose that the substrate comprises a conductive material or bulk GaN with the density as claimed, "it would have been obvious to one of ordinary skill in the art at the time the invention was made to form the substrate of Hasegawa et al. comprising a conductive material or bulk GN [sic], as that claimed by Applicant." Office Action at 5.

Claims 7 and 11 both depend directly from amended Claim 6. As *Hasegawa* fails to teach all of the limitations of amended Claim 6 (see above), by default, neither can *Hasegawa* teach all of the claimed limitations of Claims 7 and 11, as required by the third criterion described above. Additionally, Claim 11 requires that the GaN substrate possess a dislocation density of less than about 10^4 cm^{-1}. As such low defect GaN is quite elusive (see Application, p. 1, para. 2), it is difficult to imagine how it would be obvious to use such a material in the devices of *Hasegawa*. Accordingly, Claims 7 and 11 are not obvious in view of *Hasegawa*.

Regarding Claim 18, the Examiner contends that "Hasegawa et al. discloses the claimed invention including the device as explained in the rejection above," and that while "Hasegawa et al. does not disclose the density of the wide bandgap nanostructures...it would have been obvious to one having ordinary skill in the art at the time the invention was made to form wide bandgap nanostructures having a desired density." Office Action at 5-6.

Again, *Hasegawa* doesn't teach nanostructures that are nanoscale in two or more dimensions, only layers of nanometer thickness (see above). Such discussion of nanostructure density, i.e., number of nanostructures per square centimeter, is therefore nonsensical within the context of *Hasegawa*. Accordingly, Claim 18 is not obvious in view of *Hasegawa*.

Regarding Claims 21-24, the Examiner contends that "Hasegawa et al. discloses the claimed invention including the device as explained in the rejection above," and that while "Hasegawa et al. does not disclose that the device is operable as a solid state optical emitter, a light emitting diode, and the laser diode," that "it would have been obvious to one of ordinary skill in the art at the time the invention was made to use the device of Hasegawa et al. to operate as a solid state optical emitter, a light emitting diode, and the laser diode depending on the desired application as a matter of intended use." Office Action at 6.

Claims 21-24 all depend indirectly from amended Claim 6 and possess all of the claim limitations of amended Claim 6. As *Hasegawa* fails to teach all of the limitations of amended Claim 6, neither can it teach all of the claim limitations of Claims 21-24. Accordingly, the third criterion required for properly making an obvious-type rejection is not met. Furthermore, that *Hasegawa* teaches that their device can be used in or as a semiconductor laser is irrelevant since the devices are (structurally) substantially different (see above). Consequently, Claims 21-24 are not obvious in view of *Hasegawa*.

As a result of the foregoing, Applicant respectfully requests that the Examiner withdraw the rejection of Claims 7, 11, 18 and 21-24 under 35 U.S.C. § 103(a) as being obvious in view of *Hasegawa*.

V. CONCLUSION

It is believed that each of the claims now pending in the application is allowable, and that the application as a whole is in proper form and condition for allowance. Examination and allowance is therefore respectfully requested, such that the application may advance to issuance at the earliest possible date. If the Examiner believes that the application can be placed in even better condition for allowance, he is invited to contact the undersigned at the telephone number listed below.

Respectfully submitted,

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Exhibit A

Quantum Dot Heterostructures

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Germany

JOHN WILEY & SONS
Chichester • New York • Weinheim • Brisbane • Singapore • Toronto

1 Introduction

1.1 HISTORICAL DEVELOPMENT

1.1.1 FROM ATOMS TO SOLIDS

By introducing the concept of an electronic 'bandstructure' for an ideal crystalline solid Bloch (1928) (see the textbooks of Kittel, 1963, and Ibach and Lüth, 1991) presented in the late 1920s a revolution in the world of physics dominated by research on atoms. In atoms the energies of bound electrons are discrete and precisely defined within the limit of Heisenberg's uncertainty relation. In solids the electron energy is a multivalued function of momentum resulting in energy bands, continuous densities of states, and gaps. The wavefunctions became completely delocalized in real space. Central in Bloch's theory is an *infinite* extension of the regular array of lattice points in all three dimensions of space. The restriction of the theory to infinite bodies (Fig. 1.1) was regarded as being meaningless from any practical point of view, except next to surfaces. Still small crystallites of a few micrometers in size are very large compared to next-neighbor distances. No observable deviations from the predictions for an infinitely extended crystal were expected, even for small objects.

1.1.2 FROM SOLIDS TO 2D HETEROSTRUCTURES

If the carrier motion in a solid is limited in a layer of a thickness of the order of the carrier de Broglie wavelength (or mean free pass, if this number is smaller), one will observe effects of size quantization. The de Broglie wavelength λ depends on the effective mass m_{eff} of the carrier and on temperature T:

$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{(3m_{\mathrm{eff}}kT)}} = \frac{1.22\,nm}{\sqrt{(E_{kin}/[eV])}} \qquad (1.1)$$

The mass of charged carriers entering Eq. (1.1) is not the free electron mass but the effective mass of the electron (or hole) in the crystal. As this mass can be much smaller than the free electron mass, size quantization effects can be already pronounced at a thickness ten to a hundred times larger than the lattice constant.

The idea of using ultra-thin layers for studies of size quantization effects was already popular by the late 1950s and early 1960s (see the review by Lutskii, 1970). The main object of research at this time were thin films of semimetals (e.g. Bi) on mica substrates obtained by vacuum deposition. However, thin films of metals and semiconductors were also studied. For these films of Bi (Lutskii and Kulik, 1968) and InSb (Filatov and Karpovich, 1968) the effect of the increase of the effective

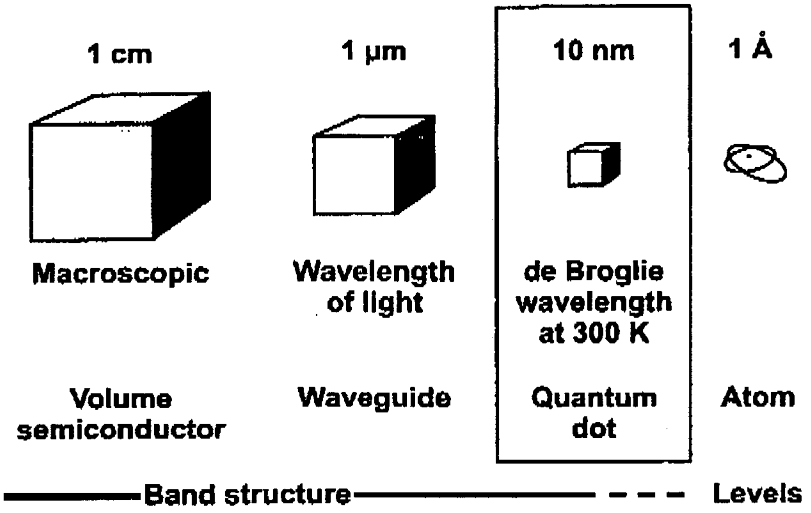

Fig. 1.1 Schematic comparison of typical dimensions of bulk material, waveguides for visible light, quantum dots, and atoms

bandgap with decreasing film thickness was demonstrated. In 1962 Keldysh (1962) considered theoretically the motion of electrons in a crystal with superimposed periodic potential having a period much larger than the lattice constant. In this work the appearance of minizones and negative differential resistance has been predicted. The use of intense sound waves was proposed to modulate the potential. In 1963 Davies and Hosack (1963) proposed to use five-layer 'metal–dielectric–metal–dielectric–metal' double-barrier structures with an ultra-thin intermediate metal layer and dielectric barriers in order to observe the effect of resonant tunneling of electrons. This effect occurs when the Fermi energy crosses the size quantization level in the ultra-thin metal layer upon variation of an external electric field. Independently in 1963 the idea of using resonant tunneling of electrons in double-barrier structures for obtaining negative differential resistance had been proposed by Iogansen (1963) for semiconductor structures with dielectric barriers. Tunneling effects in structures with large numbers of quantum wells were also considered (Iogansen, 1964).

Although this mostly theoretical work found large recognition, experimental studies were limited by insufficient technology at this time. To realize quantum size effects in an ultra-thin layer one needs to have mirror-like reflection of carriers from the surface and/or interface and a large carrier mean free pass parallel to the interface. If the boundaries are rough and the material in their vicinity is damaged, the possibilities of observing size quantization effects are very limited.

With the advent of novel epitaxial deposition techniques like molecular beam epitaxy and somewhat later metal organic chemical vapor deposition in the late

1960s the counter-revolution started. Suc
layers, a few lattice constants thick, of a se
with a larger bandgap, restricting carrie
1969–70 Esaki and Tsu proposed the u
heterostructures (superlattices) for the cre
width of minizones for carrier transport a
1970). They also proposed formation of c
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lattices and quantum wells. Another impo
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in 1970 (Kazarinov and Suris, 1971, 1972
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after lattice-matched GaAs/AlGaAs struc
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of creating unipolar long-wavelength l
electron size quantization subbands was
and Suris, 1971). Such lasers, so-called
quarter of a century later (Faist *et al.*, 19
bandgap engineering by using strained c
(1982).

Particularly impressive results have ari
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character of the absorption spectrum re
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thickness resulted in a shift of the step
studies also underlined the tremendously
and Bimberg, 1990; Christen *et al.*, 1
properties of excitons localized in pote
increased exciton binding energies, oscil
excitons were demonstrated. Excitonic
importance for some device applicatio
bistable elements (Miller *et al.*, 1984; M

1.1.3 FROM 2D HETEROSTRUCTUR

By the end of 1980s the main propertie
rather well understood and the interest o
further reduced dimensionality—to qu
quantum dots (QDs). Complete reductio
a quantum well in two dimensions to
localization in all three dimensions and

1960s the counter-revolution started. Suddenly it was possible to insert coherent layers, a few lattice constants thick, of a semiconductor of lower bandgap in a matrix with a larger bandgap, restricting carrier movement to only two dimensions. In 1969–70 Esaki and Tsu proposed the use of multilayer periodic semiconductor heterostructures (superlattices) for the creation of artificial materials with controlled width of minizones for carrier transport along the superlattice axis (Esaki and Tsu, 1970). They also proposed formation of delocalized states and negative differential resistance for high-speed electrons reaching the minizone boundary in *nipi* superlattices and quantum wells. Another important effect regarding device applications is *sequential tunneling* in superlattices that was considered first by Kazarinov and Suris in 1970 (Kazarinov and Suris, 1971, 1972). One of the first of these superlattices was grown, also in 1970, by Alferov in the $GaP_{0.3}As_{0.7}/GaAs$ material system (Alferov *et al.*, 1971). A clear demonstration of size quantization effects became possible only after lattice-matched GaAs/AlGaAs structures with planar interfaces were realized by molecular beam epitaxy. In 1974 Chang *et al.* (1974) observed the effect of resonant tunneling, proving the application of quantum mechanics to describe transport phenomena in ultra-thin semiconductor heterostructures. The possibility of creating unipolar long-wavelength laser using radiative transitions between electron size quantization subbands was also considered at that time (Kazarinov and Suris, 1971). Such lasers, so-called 'cascade' lasers, have been realized one quarter of a century later (Faist *et al.*, 1994a, 1994b). The extended possibilities for bandgap engineering by using strained quantum wells were described in Osbourn (1982).

Particularly impressive results have arisen from optical studies of quantum wells and superlattices. In 1974 Dingle *et al.* (1974) directly observed the step-like character of the absorption spectrum related to the two-dimensional character of the density of states in quantum wells (Fig. 1.2). A decrease in the GaAs layer thickness resulted in a shift of the steps toward higher photon energies. Optical studies also underlined the tremendously increased role of excitonic effects (Christen and Bimberg, 1990; Christen *et al.*, 1990) and demonstrated zero-dimensional properties of excitons localized in potential fluctuations of quantum wells. Much increased exciton binding energies, oscillator strengths and temperature stability of excitons were demonstrated. Excitonic effects were found to be of supreme importance for some device applications, such as optical modulators or optical bistable elements (Miller *et al.*, 1984; Miller, 1990).

1.1.3 FROM 2D HETEROSTRUCTURES TO QUANTUM DOTS

By the end of 1980s the main properties of quantum wells and superlattices were rather well understood and the interest of researchers shifted toward structures with further reduced dimensionality—to quantum wires (Kapon *et al.*, 1989) and quantum dots (QDs). Complete reduction of the remaining 'infinite' extension of a quantum well in two dimensions to atomic values (Fig. 1.1) leads to carrier localization in all three dimensions and breakdown of the classical band structure

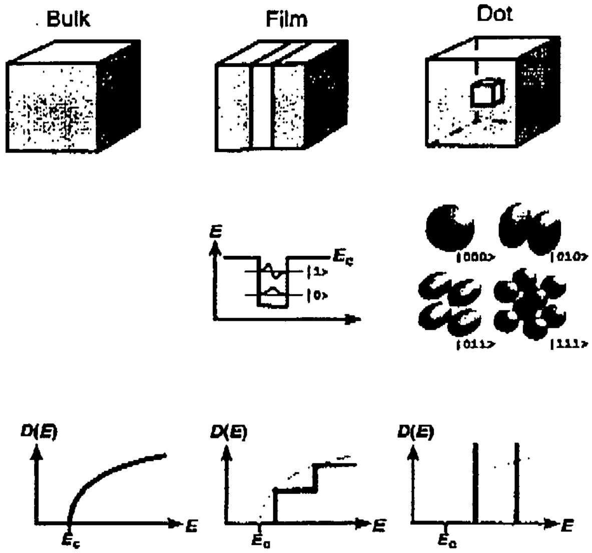

Fig. 1.2 Nature of electronic states in bulk material, quantum wells, and quantum dots. Top row: schematic morphology, center row: quantized electronic states, bottom row: density of electronic states

model of a continuous dispersion of energy as a function of momentum. The resulting energy level structure of quantum dots is discrete (Fig. 1.2), like in atomic physics, and the physical properties of quantum dots in many, although not all, respects resemble those of an atom in a cage. A profound size-dependent change of all macroscopic material properties as compared to the bulk occurs. A qualitative measure when size quantization effects are important and energy separation of sublevels is sufficiently large is again the de Broglie wavelength (Eq. 1.1), now restricting geometry in all three dimensions. A typical size of such a dot is 10 nm and it may still contain 10^4 or more atoms.

The study of single quantum dots and ensembles of quantum dots presents a new chapter in fundamental physics. Moreover, many applications of QDs for novel devices have been predicted, such as single electron transistors or quantum dot lasers. Such devices have exciting novel properties enabling new concepts and systems for many different fields of our society, ranging from information technology to environmental protection.

The road to develop quantum dots useful for devices has been full of detours and obstacles. The first realization of quantum dots were nano-size semiconductor inclusions (e.g. CdSe) in glass (Rocksby, 1932), which have been commercially available as color filters for decades (Fig. 1.3a). Quantum confinement effects in such a system were confirmed experimentally by Ekimov and Onushenko (1984). The usefulness of such color glasses for switches was investigated at a very early

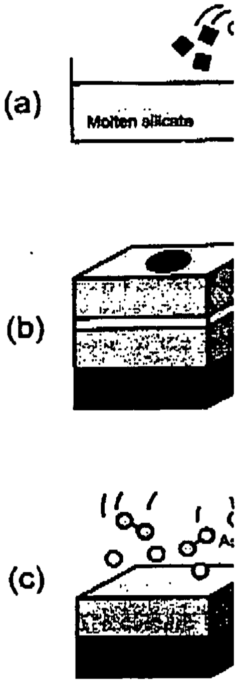

Fig. 1.3 Schematic representation o
(a) microcrystallites in glass, (b) artifi
growth of nanostructures

stage. The electrically isolating m
in electronic and optoelectronic
developed, one of them being arti
dimensional regions (Fig. 1.3b).

In the last few years nanostru
organization effects, e.g. occurrin
1.3c). These effects are also called
and kinetic ordering mechanisms t
of islands within a matrix for many
tion' in other fields of science, in
equilibrium. In contrast, QD forma

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strained heterosystems. The fabric
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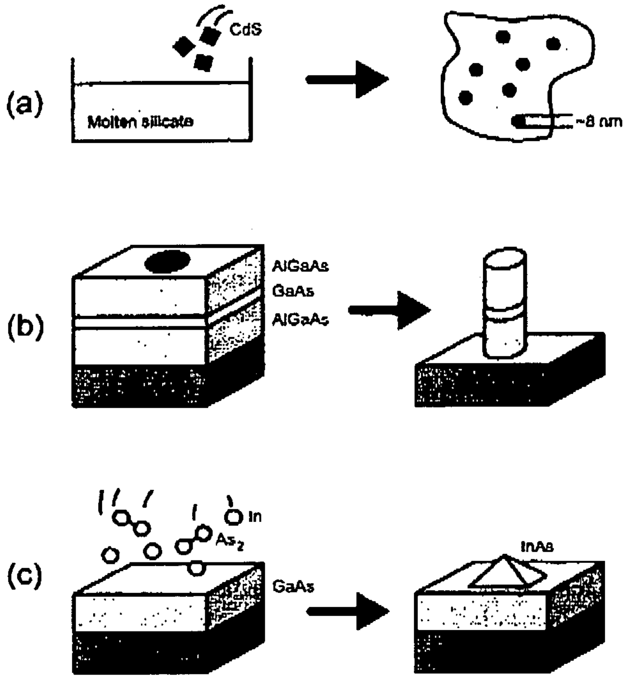

Fig. 1.3 Schematic representation of different approaches to fabrication of nanostructures: (a) microcrystallites in glass, (b) artificial patterning of thin film structures, (c) self-organized growth of nanostructures

stage. The electrically isolating matrix, however, prohibits electric injection and use in electronic and optoelectronic devices. Many alternative approaches have been developed, one of them being artificial patterning of thin layer structures into three-dimensional regions (Fig. 1.3b).

In the last few years nanostructures have been successfully realized using self-organization effects, e.g. occurring during growth of strained heterostructures (Fig. 1.3c). These effects are also called self-ordering or self-assembly. Both thermodynamic and kinetic ordering mechanisms together can create unique three-dimensional patterns of islands within a matrix for many different material systems. The word 'self-organization' in other fields of science, in particular biology, is used for systems away from equilibrium. In contrast, QD formation is in many cases an equilibrium process.

The self-organization effects discussed in this book are a general phenomenon of strained heterosystems. The fabrication process of such quantum dots is compatible with present optoelectronic device technology. A beautiful and well-understood model system for which many examples of results will be presented is InGaAs/AlGaAs. This material combination appears at the moment to be the most promising candidate for immediate device applications. Exciting reports on self-organized quantum dots fabricated in other III–V systems like InP/InGaP, Sb-containing systems such as (In,Ga)Sb/GaAs, structures based on group III nitrides like (In,Ga,Al)N, Ge/Si, SiO_2/Si, and II–VI heterostructures emerge rapidly. In order to concentrate on the most important physics, unfortunately not all of this work can be covered here in detail.

1.2 BASIC REQUIREMENTS FOR QDs IN ROOM TEMPERATURE DEVICES

Quantum dots should fulfill the following requirements in order to make them useful for devices at room temperature:

(a) Sufficiently deep *localizing potential* and small QD *size* is a prerequisite for observation and utilization of zero-dimensional confinement effects.
(b) QD ensembles should show high uniformity and a high volume filling factor.
(c) The material should be coherent without defects like dislocations.

1.2.1 SIZE

The lower size limit of a QD is given by the condition that at least one energy level of an electron or hole or both is present. The critical diameter (for a spherical QD) D_{min} depends strongly on the band offset of the corresponding bands in the material system used. An electron level exists in a spherical quantum dot if the confinement potential, defined by the conduction band offset (in a type-I heterostructure) ΔE_c (see Eq. 5.41), exceeds the value:

$$D_{\min} = \frac{\pi\hbar}{\sqrt{(2m_c^* \, \Delta E_c)}} \qquad (1.2)$$

where m_c^* is the effective electron mass. Assuming a conduction band offset value of ~0.3 eV for GaAs/$Al_{0.4}Ga_{0.6}As$ heterostructures, the diameter of the quantum dot should be larger than 4 nm. This is the lower limit of the QD size. In quantum dots of this or slightly larger size the separation between the electron level and the barrier energy is very small, and at finite temperatures thermal evaporation of carriers from QDs will result in their depletion. For the InAs/AlGaAs system the conduction band offset is much larger while the electron effective mass is smaller, so the product of $\Delta E_c m_c^*$ is comparable and the critical size is also about 3–5 nm depending on the nonparabolicity effects in the InAs conduction band.

There also exists a limit for the maximum size of a QD. A thermal population of higher-lying energy levels is undesirable for particular devices like, for example, lasers. The condition to limit thermal population of higher-lying levels to $5\% \approx e^{-3}$ can be written as

$$kT \leqslant \frac{1}{3}(E_2^{QD} - E_1^{QD}) \qquad (1.3)$$

Here E_1^{QD} and E_2^{QD} are the energies o
respectively. This equation establishes
size of GaAs/AlGaAs QDs of ~12 nn
electron levels are considered. This n
operating temperature.

Consideration of hole quantization in
those derived for electrons above. Th
separation between hole sublevels at roc
be 5–6 nm for both material systems dis
with sufficient sublevel separation for
ture) are difficult to realize in most III-
InAs/AlGaAs because of the large ele
tions, where confinement has to be real
of different size requirements for simu
ment does not exist. In group III nitri
electron and hole masses, strong loc
possible.

1.2.2 UNIFORMITY

If a single device is based on more th
arises. Even if an individual device is b
important in order to attain similar cha
all structural parameters of a QD such
subject to random fluctuations, even
most cases a dense array of equisized

The main impact of size fluctuatio
electronic levels. Such variation is typ
that relies on the integrated gain in a
laser (Sections 5.4 and 8.2), the inhom
small as possible. This means that for
ensure the smallest possible size and s
plexing is attempted, a certain width of
(e.g. see Section 8.1). In order to rea
luminescence spectrum, comparable
temperature (20–30 meV) for a GaAs
a size dispersion lower than 1 nm.

If device operation is based on many
of dots is necessary to obtain a given
minimum number of QDs to overcome
a given volume, making it a prerequisi
volume filling factor.

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